

**Description**

**Plasma-enhanced chemical vapor deposition process, and material containing silicon, oxygen, nitrogen, and a layer arrangement**

The invention relates to a plasma-enhanced chemical vapor deposition process, to a material containing silicon, oxygen and nitrogen, and to a layer arrangement.

Integrated circuit arrangements are produced with an ever greater packing density. This means that interconnects in metallizing layers have an ever shorter separation between them. In consequence, capacitances which are formed between the interconnects and lead to long signal delay times, to high power losses and to undesirable crosstalk, that is to say, which lead to an interaction between signals applied to adjacent interconnects, are increasing.

Silicon oxide is frequently used as a dielectric, as the isolation material between the interconnects, and its relative dielectric constant is  $\epsilon_r = 3.9$ .

So-called low-k materials, that is to say materials with a low  $\epsilon_r$  value as the material for the intermetal dielectrics, are used in order to reduce the relative dielectric constant  $\epsilon_r$ , and this leads to a reduction in the value of the coupling capacitances between interconnects embedded in an insulation material.

It is also known from the prior art, that cavities are produced between interconnects within an interconnect layer, in order to reduce the value of the relative dielectric constant, and thus the value of the coupling capacitance. The insulating dielectric which governs the capacitance between the interconnects has a relative dielectric constant  $\epsilon_r$  which is approximately

equal to unity in the area of the cavities. The interconnects themselves are surrounded by a material layer, composed of silicon oxide or a low-k material, in order to decouple them from the surrounding area.

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The high coupling capacitances  $C$  between adjacent interconnects, which are becoming ever greater as circuits become increasingly miniaturized, are leading together with the resistance  $R$  of an interconnect to an RC switching delay for signals transported on the interconnects. This RC switching delay can be reduced using airgaps as an alternative to low-k materials, since the use of airgaps between interconnects, as the isolation material between metallization paths, considerably reduces the effective dielectric constant  $\epsilon_r$ . By way of example, [1] to [4] disclose possible ways to provide airgaps.

In order to seal and to close a cavity between adjacent interconnects from the outside, a cavity or trench such as this in a layer arrangement can be sealed by the deposition of a covering layer, covering the trench. When sealing a trench-like cavity between interconnects, the aim is to deposit the material of such a covering layer well on the uppermost layer, but in contrast not to enter the trench and thus not to undesirably fill the cavity between adjacent interconnects with material, which would once again increase the relative dielectric constant  $\epsilon_r$  between the interconnects.

Silicon oxide formed by ozone-activated decomposition of tetraethyl orthosilicate (TEOS) (so-called "ozone/TEOS") is suitable as a material for a covering layer such as this, and can be deposited selectively well on silane-based silicon oxide as the material of the uppermost layer, but not in contrast on the silicon

nitride as the material in the interior of the trench. Selective deposition means that the material to be deposited as the covering layer to close the cavity grows on silane-based silicon oxide, but in contrast  
5 does not grow, or grows at only a very slow rate, on silicon nitride.

Thus, according to the prior art, silicon nitride is frequently used as the material between airgap  
10 structures between interconnects, while in contrast a surface layer on which a covering layer is to be grown in a layer arrangement such as this is frequently formed from silane-based silicon oxide. However, this material configuration has the disadvantage that an RC  
15 switching delay which is excessive for many applications occurs, because of the high relative dielectric constant of silicon nitride ( $\epsilon_r = 8$ ).

[5] discloses a method for formation of a silicon  
20 oxynitride layer by means of a CVD method, using a plasma and a mixing gas, with the mixing gas containing an organic silane gas and a nitride gas on and between interconnects on a semiconductor chip. The silicon oxynitride layer has good edge coverage, according to  
25 the statements in [5].

Other methods for formation of a silicon oxynitride layer with good edge coverage are described in [6] and  
30 [7].

[8] describes the formation of a structure with airgaps between the interconnects. The layer formed with airgaps is, however, formed using  $\text{SiH}_4$ , and thus using an inorganic silicon precursor material.

35 Another airgap structure is described in [9], in which case this structure is produced using only one "airgap layer" and, in order to increase the "aspect ratio" between the interconnects and thus in order to

automatically form airgaps, a pad oxide layer, which is additionally applied to the interconnects.

5 The invention is based in particular on the problem of providing a material, a method for production of the material, and a layer arrangement with this material, which material has a sufficiently low relative dielectric constant and cannot be deposited, or can be deposited only poorly selectively, on ozone/TEOS.

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The problem is solved by a plasma-enhanced chemical vapor deposition process, by a material containing silicon, oxygen and nitrogen, and by a layer arrangement having the features as claimed in the independent patent claims.

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In the plasma-enhanced chemical vapor deposition process according to the invention for formation of a material containing silicon, oxygen and nitrogen, nitrogen material is supplied using an organic silicon precursor material during the supply of the silicon material and oxygen material.

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Furthermore, according to the invention, a material containing silicon, oxygen and nitrogen is provided, and is produced using the features described above, according to the plasma-enhanced chemical vapor deposition process.

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30 The layer arrangement according to the invention contains a substrate and two electrically conductive structures on the substrate. At least a subarea between the two electrically conductive structures is free of material. Material containing silicon, oxygen and nitrogen and having the features described above is formed at least partially on and/or between the two electrically conductive structures. Furthermore, the layer arrangement contains an intermediate layer composed of electrically insulating material on the

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material which contains silicon, oxygen and nitrogen, and a covering layer which is formed selectively on the intermediate layer, by means of which the material-free area between the two electrically conductive structures is sealed from the environment.

One basic idea of the invention is the provision of a production method for a material containing silicon, oxygen and nitrogen, by means of which method a material is produced which contains predominantly silicon-oxygen components and thus has a relative dielectric constant which is similarly low to that of silicon oxide ( $\epsilon_r = 3.9$ ). The material containing silicon, oxygen and nitrogen and produced on the basis of the plasma-enhanced chemical vapor deposition process according to the invention additionally contains rather small amounts of nitrogen (preferably in the single-digit percentage range). The nitrogen component of the material containing silicon, oxygen and nitrogen and produced by means of the method according to the invention results, as can be seen, in characteristics similar to silicon nitride with regard to the capability to deposit ozone/TEOS. In other words, the material of the invention is highly unsuitable for allowing ozone/TEOS to be deposited on it. The combination of a low-k-value and a small tendency to be used as a carrier for the deposition of ozone/TEOS results in the material produced according to the invention being excellently suitable for use as an intermetal dielectric for an integrated circuit having airgap structures.

In other words, the material produced according to the invention essentially has the good dielectric characteristics of silicon oxide (that is to say a low relative dielectric constant value and thus a short RC switching delay), while at the same time the material composition (probably in particular the nitrogen component in it) has the effect that the material which

is formed on the basis of an organic precursor has material characteristics similar to those for silicon nitride in terms of the selective deposition of ozone/TEOS. This thus results in an ideal material for the intermetal dielectric between interconnects in a low-k arrangement. The good mechanical stability of the material also allows airgaps to be formed between structures of the material.

The invention thus makes it possible to replace the silicon nitride which is used according to the prior art as the material between airgaps by a material based on silicon oxide, without losing the advantages of selective deposition.

According to the invention, this material is produced in that, apart from an organic silicon precursor material as the source for the silicon component and the oxygen component of the material according to the invention, nitrogen material is additionally introduced into the PECVD process chamber ("plasma enhanced chemical vapor deposition"), thus resulting in the material according to the invention. Clearly, when using this method, small amounts of nitrogen are incorporated in a matrix based essentially on silicon-oxide material, and this leads to the advantageous combination of material characteristics.

Silicon oxide is frequently deposited using a plasma-activated TEOS process (so-called "PE-TEOS"). Based on the observation that no ozone/TEOS deposition, or only a very small amount of ozone/TEOS deposition, takes place on silicon nitride, nitrogen is added, according to the invention, to the PE-TEOS process. The incorporation of small amounts of nitrogen, typically in the percentage range, makes it possible to greatly increase the selectivity of the ozone/TEOS deposition so that no deposition of ozone/TEOS, or only an extremely small amount of deposition of ozone/TEOS,

takes place on the layer, in a similar manner to that with silicon nitride. At the same time, the characteristics of silicon oxide are largely retained. The effective dielectric constant of an airgap structure with the modified PE-TEOS decreases, depending on the geometry, from values in the region of three to values of about two, in comparison to the variants with silicon nitride.

10 The layers containing silicon oxide, produced using the method according to the invention and with nitrogen material incorporated in them, typically have a refractive index of  $n = 1.5$ , while in contrast silicon oxide produced by means of thermal oxidation has a refractive index of 1.45. The nitrogen content of the material according to the invention is typically in the atomic percentage range. Deposition of ozone/TEOS does not take place, or takes place only very poorly, on this type of silicon oxide provided with small amounts of nitrogen.

The essential factor for achieving the advantageous material characteristics of the material according to the invention is the use of an organic (that is to say based on carbon compounds) silicon precursor material, preferably tetraethyl orthosilicate (TEOS), also referred to as tetraethoxysilane. For example, the material with the advantageous characteristics cannot be obtained using the inorganic material silane ( $\text{SiH}_4$ ).

30 The plasma-enhanced chemical vapor deposition process (PECVD) used according to the invention is a specific technique within the more general CVD method ("chemical vapor deposition").

35 The CVD method is a coating technology for deposition of thin layers from the gas phase on a solid substrate. The principle of the CVD method is that gaseous initial materials, so-called precursors, are passed over a

substrate and are chemically decomposed into their components, as a result of which a new layer grows on the substrate surface. The decomposition of the precursors is generally carried out thermally, that is to say by heating the substrate. The actual deposition takes place with the involvement of a chemical reaction. For example, a volatile gaseous component reacts with another gas to form a solid material, which is deposited on the substrate. However, the process temperatures in the CVD process are relatively high.

The plasma-enhanced chemical vapor deposition process can be carried out at considerably lower process temperatures. While, in the case of a CVD process, the vapor reaction is initiated by thermal energy by heating the substrate, a PECVD method is based on changing a gas to the plasma state in the vicinity of the substrate surface. One of the reaction products is in this case a solid substance, which is precipitated on the surface, as a result of which a new layer composed of the material according to the invention is formed. A plasma is ignited by a strong alternating electrical field in a PECVD reactor, between the substrate holder, which acts as one electrode, and a further electrode. The energy of the field breaks bonds of the gas molecules introduced into the PECVD reactor, and breaks down the gas molecules.

According to a further aspect of the invention, a method is provided for production of a layer arrangement

- in which a layer composed of oxygen material nitrogen material is formed over a substrate having a plurality of electrically conductive structures and/or over a part of the surface of the electrically conductive structures, by means of a plasma-enhanced chemical vapor deposition process, with nitrogen material being supplied, during the supply of silicon material and oxygen



material, by means of an organic silicon precursor material, with the layer of oxygen material nitrogen material being formed in such a manner that an area free of material remains between the interconnects,

- in which an intermediate layer composed of electrically insulating material is applied to the layer of oxygen material nitrogen material, and
- in which a covering layer is selectively applied to the intermediate layer, by means of which the material-free area between the electrically conductive structures is sealed from the environment, so that the material-free area forms a cavity.

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Furthermore, a layer arrangement is provided,

- having a substrate;
- having two electrically conductive structures on the substrate, with at least a subarea between the two electrically conductive structures being free of material;
- having a layer of material containing silicon, oxygen and nitrogen, which has been formed by means of a plasma-enhanced chemical vapor deposition process, with nitrogen material being supplied, during the supply of silicon material and oxygen material, by means of an organic silicon precursor material, with the layer being applied to the two electrically conductive structures in such a manner that an area free of material remains between the two electrically conductive structures,
- having an intermediate layer composed of electrically insulating material on the layer composed of material containing silicon, oxygen and nitrogen;
- having a covering layer, which is formed selectively on the intermediate layer, by means of which the material-free area between the two

electrically conductive structures is sealed from the environment.

In particular, as can be seen, the invention has identified that the material of the covering layer is not deposited on the material containing silicon, oxygen and nitrogen formed in the manner described above, thus resulting in selective deposition of the covering layer only on the intermediate layer in order to "close the airgaps", without reducing the width of the airgap between the conductive structures. This results in the airgaps being closed by means of the covering layer in a very simple manner, with one additional advantage being the low relative dielectric constant of the material containing silicon, oxygen and nitrogen.

Preferred developments of the invention result from the dependent claims.

A material containing oxygen is preferably used as the organic silicon precursor material. This material containing oxygen may be used as an oxygen source in order to form the material according to the invention containing silicon, oxygen and nitrogen.

It is particularly advantageous to use tetraethyl orthosilicate (TEOS), that is to say  $(C_2H_5O)_4Si$ , as the precursor material. This material represents a particularly advantageous silicon source and oxygen source for the material containing silicon, oxygen and nitrogen, according to the invention, in which nitrogen material, which is introduced simultaneously, is incorporated as a result of the chemical processes during decomposition of the TEOS material.

Alternatively, but still within the scope of the invention, the following materials may be used, for example, as an organic silicon precursor material,

methyltriethoxysilane (MTrEOS), dimethyldiethoxysilane (DMDEOS), trimethylethoxysilane (TrMEOS) and/or tetramethylsilane (TMS).

- 5 Tetraethyl orthosilicate (TEOS) and nitrogen ( $N_2$ ) are preferably used as precursors for the plasma-enhanced chemical vapor deposition process according to the invention, with the flow-rate ratio of tetraethyl  
10 1:1. The flow-rate ratio is the quotient of the flow rates (for example in SCCM, standard cubic centimeters per minute) of the two individual components.

Furthermore, the flow-rate ratio of tetraethyl  
15 orthosilicate to nitrogen is preferably set between 1:5 and 1:2.

It is particularly advantageous to set the flow-rate ratio of tetraethyl orthosilicate to nitrogen between  
20 11:40 and 7:20.

Helium can be supplied as a carrier gas during the plasma-enhanced chemical vapor deposition process.

- 25 The pressure in the process chamber is preferably set between 440 Pa and 1750 Pa, furthermore preferably between 700 Pa and 1100 Pa.

The temperature in the process chamber can  
30 advantageously be between 300°C and 500°C, with a temperature between 380°C and 430°C being particular advantageous.

The material containing silicon, oxygen and nitrogen  
35 according to the invention and produced using the plasma-enhanced chemical vapor deposition process according to the invention will be described in more detail in the following text. Refinements of the plasma-enhanced chemical vapor deposition process also

apply to the material containing silicon, oxygen and nitrogen, and refinements of the material containing silicon, oxygen and nitrogen also apply to the plasma-enhanced chemical vapor deposition process.

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The material containing silicon, oxygen and nitrogen preferably contains between 0.1 percent by atomic weight and 10 percent by atomic weight of nitrogen. The material according to the invention furthermore preferably contains between 0.5 percent by atomic weight and 5 percent by atomic weight of nitrogen. It is particularly advantageous for the parameters for the plasma-enhanced chemical vapor deposition process to be set in such a manner that the material contains between 1.4 percent by atomic weight and 2.3 percent by atomic weight of nitrogen. This makes it possible to achieve a particular good balance between a low dielectric constant and particularly poor selectivity with regard to the growth of ozone/TEOS.

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The ratio, in terms of percentage by atomic weight, between oxygen and silicon is preferably between 1.8 and 1.99. In other words, the material containing silicon, oxygen and nitrogen is modified in comparison to stoichiometric silicon oxide with a ratio, in terms of percentage by atomic weight, between oxygen and silicon of two, such that oxygen material is clearly (at least partially) replaced by the additional nitrogen material.

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In addition to the silicon material, the oxygen material and the nitrogen material, the material according to the invention may have between 0.4 percent by atomic weight and 2.4 percent by atomic weight of carbon. It is also possible for the carbon to contribute to the advantageous material characteristics, since the aim according to the invention is achieved only by using an organic silicon

precursor material, that is to say one containing carbon.

Furthermore, the material according to the invention  
5 and containing silicon, oxygen and nitrogen may have  
between 3 percent by atomic weight and 13 percent by  
atomic weight of hydrogen.

Particularly advantageous material characteristics are  
10 achieved by a material with the overall formula  
 $\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$ . Each of the index numbers (1.00,  
1.90, etc.) in the stated overall formula may vary by  
twenty percent upwards or downwards, furthermore  
preferably by 10 percent, and even further preferably  
15 by 3 percent, without losing the advantageous  
characteristics of the material.

Refinements of the layer arrangement according to the  
invention will be described in the following text.  
20 Refinements of the material containing silicon, oxygen  
and nitrogen also apply to the layer arrangement, and  
vice versa.

In the case of the layer arrangement according to the  
25 invention, the intermediate layer may be formed from  
silane-based ( $\text{SiH}_4$ ) silicon oxide. If a covering layer  
composed of silicon oxide is then selectively  
deposited, and is formed on the basis of ozone-  
activated tetraethyl orthosilicate, then this results  
30 in a layer arrangement which is reliably closed off  
from the exterior, since the material of the covering  
layer can clearly grow over a trench in the layer  
arrangement. At the same time, the material combination  
prevents the trench from being partially filled with  
35 covering-layer material during the growth of a covering  
layer such as this, which results from the poor  
deposition capability of the material of the covering  
layer on the material according to the invention within  
the trench.

It should be noted that the precise process parameters for production of the material according to the invention depend on the process chamber etc.

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Exemplary embodiments of the invention will be explained in more detail in the following text and are illustrated in the figures, in which:

10 Figure 1 shows a cross-sectional view of a layer arrangement according to a first exemplary embodiment of the invention

15 Figure 2 shows an electron-microscope cross-sectional view of a layer arrangement without use of the material according to the invention,

20 Figure 3 shows an electron-microscope cross-sectional view of a layer arrangement using the material according to the invention,

25 Figure 4 shows another electron-microscope cross-sectional view of a layer arrangement using the material according to the invention,

Figure 5 shows a cross-sectional view of a layer arrangement according to a second exemplary embodiment of the invention,

30 Figure 6 shows a cross-sectional view of a layer arrangement according to a third exemplary embodiment of the invention.

35 Identical or similar components in the various figures are provided with the same reference numbers.

The illustrations in the figures are schematic, and not to scale.

Step	1. Fill	2. STAB	3. DEPOSIT	4. PUMP
Process chamber	Only A	Only A	Only A	Only A
Step end control	By time	By time	By time	By time
Maximum step time	10.0 s	10.0 s	60.0 s	5.0 s

End point selection	No end point	No end point	No end point	No end point
Pressure	Controlled to 880 Pa	Controlled to 880 Pa	Controlled to 880 Pa	Restrictor fully open
RF power, match, mode	0 W, auto, B-to-B	0 W, auto, B-to-B	900 W, auto, B-to-B	0 W, auto, B-to-B
RF tune nominal value	0.0 V	0.0 V	0.0 V	0.0 V
RF2 power, match	0 W, auto	0 W, auto	0 W, auto	0 W, auto
Temperature susceptor	415°C	400°C	400°C	400°C
Temperature ramp	0.0°C/s	0.0°C/s	0.0°C/s	0.0°C/s
Purge	Off	Off	Off	Off
Susceptor spacing	250 mils	250 mils	250 mils	250 mils
Gas flows	02:700 sccm He:2500 sccm TEOS:700 sccm N2:2000 sccm	02:155 sccm He:850 sccm TEOS:550 sccm N2:2000 sccm	02:150 sccm He:700 sccm TEOS:550 sccm N2:2000 sccm	

**Table 1**

**Table 1** shows the steps and parameters for a process procedure for a "P5000" installation from the Applied Materials<sup>TM</sup> Company by means of which material containing silicon, oxygen and nitrogen (that is to say a modified PE-TEOS layer) can be produced according to one preferred exemplary embodiment of the invention.

The procedure for this process for the production of the material according to the invention containing silicon, oxygen and nitrogen will be described in the following text, on the basis of one preferred exemplary embodiment of the invention with reference to Table 1.

First of all, in a first step, the so-called gas filling step, the pressure in the process chamber is set to 880 Pa with a maximum step time of 10.0 s. With the radio-frequency power switched off, the temperature of the susceptor is raised from the standard temperature of 400°C to 415°C, so that the susceptor does not cool down when the cold silicon wafer is subsequently introduced. The gas flows are set to be 700 sccm (standard cubic centimeters per minute) for an O<sub>2</sub> component (oxygen), 2500 sccm for a helium carrier gas, a flow rate of 700 sccm for TEOS as an organic silicon precursor, and a flow rate of 2000 sccm for nitrogen.

In a second process step, referred to as a stabilization step, the maximum step time of 10.0 s is kept to. The pressure in the process chamber is still kept at 880 Pa. The temperature of the susceptor is then changed to 400°C, without radio-frequency power, and the gas flows are modified such that the O<sub>2</sub> component is changed to 155 sccm, the helium carrier-gas component to 850 sccm, the TEOS component to 550 sccm, and the nitrogen component to 2000 sccm.

In a third process step, which is referred to as the deposition step, the step time is set as appropriate



for the desired layer thickness. A step time of 60.0 s, for example, results in the growth of a layer with a thickness of about 450 nm. The pressure in the chamber is kept at 880 Pa, and radio frequency is applied, with  
5 a power level of 900 W. The temperature of the susceptor is kept at 400°C. The gas flows are set as follows: the O<sub>2</sub> component is set to 150 sccm, the helium component to 700 sccm, the TEOS component is controlled at 550 sccm, and the nitrogen component is controlled  
10 at 2000 sccm.

In a fourth method step, referred to here as the pumping process, the maximum step time is reduced to 5 s. With regard to the pressure, the restrictor is  
15 opened completely, and the radio-frequency power is reduced to 0 W. Furthermore, the gas flows of oxygen, helium, TEOS and nitrogen are reduced.

A layer arrangement 100 according to a first exemplary embodiment of the invention will be described in the  
20 following text with reference to **figure 1**.

The layer arrangement 100 has a silicon substrate 101, on which a first copper interconnect 102 and a second  
25 copper interconnect 103 are formed. The area between the two electrically conductive structures 102, 103 is free of material, specifically the area of airgaps 107. Si<sub>1.00</sub>O<sub>1.90</sub>H<sub>0.27</sub>C<sub>0.045</sub>N<sub>0.06</sub> material 104 produced according to the invention is formed on the two electrically  
30 conductive structures 102, 103. A silane-based silicon-oxide intermediate layer 105 is applied to the Si<sub>1.00</sub>O<sub>1.90</sub>H<sub>0.27</sub>C<sub>0.045</sub>N<sub>0.06</sub> material 104. An ozone/TEOS covering layer 106 is formed (that is to say silicon oxide formed by ozone-activated decomposition of  
35 tetraethyl orthosilicate) on the silane-based silicon-oxide intermediate layer 105, by means of which the material-free area 107 between the two electrically conductive structures 102, 103 is sealed from the environment.

The  $\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$  material 104 according to the invention partially covers the copper interconnects 102, 103. The material according to the invention has substantially the same dielectric characteristics as those of silicon oxide. The effective dielectric constant of the area between the interconnects 102, 103 which is formed by the airgaps 107 with  $\epsilon_r$  of approximately unity (and possibly  $\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$  material 104 with  $\epsilon_r$  of approximately 3.9) is thus very low. Thus, when signals are applied to the copper interconnects 102, 103, the RC signal delay times are short, thus avoiding undesirable crosstalk between the interconnects 102, 103. During closure or sealing, that is to say during complete coverage, of the trench which is formed from components 102 to 105, the ozone/TEOS covering layer 106 is formed selectively only on the silane-based silicon-oxide intermediate layer 105, thus avoiding undesirable selective deposition of covering layer material on the  $\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$  material 104 because of the nitrogen component contained in the  $\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$  material 104 according to the invention. The covering layer 106 can thus reliably seal the cavity from the exterior, without any material being undesirably introduced into the airgaps 107, which would lead to an undesirable increase in the effective  $\epsilon_r$  value between the interconnects 102, 103.

Differences between a conventional material and the material provided according to the invention will be described in the following text with reference to figure 2 and figure 3 and using electron-microscope photographs.

**Figure 2** shows an electron-microscope photograph 200 of a cross-sectional view of a layer arrangement in which conventional TEOS material has been used as the dielectric 204 between airgaps 202. As can be seen from figure 2, during the formation of a covering layer 201

by means of a selective O<sub>3</sub>/TEOS deposition process, an edge area 203 between the airgaps 202 and the dielectric 204 has been undesirably covered with material, thus undesirably increasing the dielectric  
5 constant of the airgap area.

In contrast to this, the electron-microscope photograph 300 shown in **figure 3** shows a layer arrangement according to the invention in which a covering layer  
10 201, formed by means of a selective ozone/TEOS deposition process, does not form any structures on sidewalls of airgaps 202. This is because Si<sub>1.00</sub>O<sub>1.90</sub>H<sub>0.27</sub>C<sub>0.045</sub>N<sub>0.06</sub> material 301 is used as the material between airgaps 202 according to the  
15 invention, instead of the conventional dielectric layer 204 from figure 2. This results in a low dielectric constant in the area of the airgaps 202, which is extremely advantageous for low-k applications.

20 **Figure 4** shows another electron-microscope photograph 400 in the form of a cross-sectional view of a layer arrangement according to the invention, in which copper interconnects 401 are formed in addition to the components shown in figure 3. Since the effective  
25 relative dielectric constant between the copper interconnects 401 is reduced because of the material 301 according to the invention between the airgaps 202 (since, according to the invention, undesirable side-wall coverage of the airgaps 202 with ozone/TEOS  
30 material of a covering layer 201 is avoided), the RC delay times of the circuit arrangement 400 shown in figure 4 are significantly better than those in the prior art.

35 A cross-sectional view of a layer arrangement 500 according to a second exemplary embodiment of the invention will be described in the following text with reference to **figure 5**.

The interconnect arrangement 500 has a base substrate 502. Silicon dioxide ( $\text{SiO}_2$ ) is chosen as the material for this base substrate 502. Two interconnects 503 composed of aluminum or copper are formed in the base substrate 502.

Both the interconnects 503 and the base substrate 502 are covered by a first stop layer 504. A layer stack comprising, successively, a first isolation layer 505, a second stop layer 506, a second isolation layer 507, a third stop layer 508, a third isolation layer 509, a buffer layer 510 and a supporting layer 511 is arranged above the first stop layer 504.

According to this exemplary embodiment, the first stop layer 504, the second stop layer 506, the third stop layer 508 and a fourth stop layer 512 are each formed from silicon nitride ( $\text{Si}_3\text{N}_4$ ), which is electrically insulating. According to this exemplary embodiment,  $\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$  material produced according to the invention is used as the material for the first isolation layer 505, for the second isolation layer 507, for the third isolation layer 509 and for the buffer layer 510. Plasma-enhanced silicon dioxide ( $\text{SiO}_2$ ) based on silane ( $\text{SiH}_4$ ) is used for the supporting layer 511 (also referred to as the intermediate layer). In this case, the plasma-enhanced silicon dioxide ( $\text{SiO}_2$ ) based on silane ( $\text{SiH}_4$ ) is normally deposited using a PECVD process (PECVD, "plasma enhanced chemical vapor deposition").

The base substrate 502, the first stop layer 504, the first isolation layer 505, the second stop layer 506, the second isolation layer 507, the third stop layer 508, the third isolation layer 509 and the fourth stop layer 512 are formed in the rising direction of the layer stack. The buffer layer 510 is bounded at the top by a buffer layer surface 513. A cavity 514 is formed in the buffer layer 510 and in the layers arranged

underneath it, projects from the buffer layer surface 513 as far as the second stop layer 506 into the layers arranged underneath, and has a cavity depth  $T_H$ .

5 The cavity 514 isolates the two interconnects 503, which are arranged such that they are buried, partially replace the third stop layer 508 and the third isolation layer 509, and together define an interconnect layer. The interconnects 503 which are  
10 electrically isolated by means of the cavity 514 are arranged alongside one another with an interconnect separation A in such a manner that the respective lower interconnect surface is at a distance corresponding to an interconnect depth  $T_L$  at right angles to the buffer  
15 layer surface 513, with this depth being greater than the vertical thickness of the interconnects 503. The cavity depth  $T_H$  is greater than the interconnect depth  $T_L$ , thus reducing stray fields between adjacent interconnects 503 in the areas of the buffer layer 510  
20 directly above and below the interconnects 503. The cavity 514 has a width which is equal to the interconnect separation A.

The interconnects 503, which partially replace the  
25 third stop layer 508 and the third isolation layer 509, are electrically coupled by means of an electrical contact 515 to the interconnect 503 which is located in the base substrate 502, and, according to this exemplary embodiment, are made of the same material as  
30 the interconnect 503 which is located in the base substrate 502. For this purpose, the electrical contact 515 passes through the first stop layer 504, the first isolation layer 505, the second stop layer 506 and the second isolation layer 507.

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Furthermore, the buffer layer 510 and the supporting layer 511 are located one above the other, with the cavity 514 projecting through the buffer layer 510, and projecting partially into the supporting layer 511.

The cavity 514 is closed at the top with respect to the buffer layer surface 513 by means of a covering layer 516. The covering layer 516 is made of an isolation material which is deposited selectively and exclusively on the supporting layer 511. Silicon-dioxide ( $\text{SiO}_2$ ) based on ozone-activated tetraethyl orthosilicate ( $\text{O}_3/\text{TEOS}$ ) is used as the material for the covering layer 516. A different material may, of course, also be chosen for the covering layer 516, provided that this has the selectivity with regard to its deposition behavior as described above. The covering layer 516 is clearly designed in such a manner that it has a cutout, in the form of a gap, facing the cavity 514. In consequence, the supporting layer 511 should have an adequate depth at right angles to the buffer layer surface 513 such that the cavity 514 is also completely closed by the covering layer 516 above the cutout, in the form of a gap, in the covering layer 516.

The covering layer 516 as well as the supporting layer 511 have a common covering layer/supporting layer surface 517, which bounds these two layers 516, 511 at the top, essentially parallel to the substrate surface 501. Finally, a fifth stop layer 518 is also arranged on this covering layer/supporting layer surface 517, to which additional interconnect layers can be applied.

The geometry of the cavity 514 is preferably chosen such that the interconnect arrangement 500 has sufficiently good electrical isolation between the interconnects 503 within one interconnect layer, with an adequate reduction in the relative dielectric constant  $\epsilon_r$ . According to this exemplary embodiment, the interconnect separation A and thus the cavity 514 have a width from 400 nm to 500 nm, which is virtually the same as the width of the interconnects 503. According to this exemplary embodiment, the cavity depth  $T_H$  has a value which corresponds to twice the thickness of the

interconnects 503. According to this exemplary embodiment, the interconnects 503 have a thickness of approximately 600 nm. According to the present exemplary embodiment, the individual stop layers each  
5 have a thickness of approximately 50 nm. The isolation layers apart from the third isolation layer 509 as well as the buffer layer 510 and the supporting layer 511 each have a thickness of approximately 150 nm according to the present exemplary embodiment. Alternatively,  
10 other suitable dimensions may, of course, also be chosen.

Either the damascene technique or the metal-etching technique may be used to produce the interconnects 503.  
15 The damascene technique is preferably used when copper is used as the material for the interconnects 503, while the metal-etching technique is preferably used when aluminum is used as the material for the interconnects 503.

20 In the case of one exemplary embodiment of the invention, which is not illustrated but is essentially the same as the second exemplary embodiment of the invention which has just been described, the cavity 514  
25 may additionally also extend through the second stop layer 506 to the boundary surface between the second stop layer 506 and the first isolation layer 505. Obviously, so much material is removed from the second stop layer 506 in the area of the cavity 514 in order  
30 to enlarge the cavity 514 that the first isolation layer 505, located underneath, is just exposed. This results in the effective relative dielectric constant  $\epsilon_r$  additionally being reduced. This is because the larger cavity 514 additionally reduces interfering electrical  
35 stray fields between the interconnects 503.

**Figure 6** shows a cross-sectional view of a layer arrangement 600 (also referred to as an interconnect

arrangement 600) according to a third exemplary embodiment of the invention.

5 The interconnect arrangement 600 according to the third exemplary embodiment is essentially identical to the interconnect arrangement 500 according to the second exemplary embodiment. The differences between the interconnect arrangement 600 according to the third  
10 500 according to the second exemplary embodiment are as follows: the cavity 514 has a cavity width B parallel to the plane of the drawing with respect to the substrate surface 501, and this width B is greater than the interconnect separation A. This means that the  
15 shape of the cavity 514 is clearly comparable to an "I", or to a bone. The greater extent of the cavity 514 above and below the interconnect layer formed by the adjacent interconnects 503 contributes to an additional reduction in the effective relative dielectric constant  
20  $\epsilon_r$  in the interconnect arrangement 600. This is because the larger cavity 514 additionally reduces disturbing electrical stray fields between the interconnects 503.

25 The third stop layer 508 and the fourth stop layer 512 have a hole width C which is less than the interconnect separation A, in the area of the cavity 514. This is a consequence of the special production process, by means of which the curved cavity 514 is produced in the interconnect arrangement 600 according to the third  
30 exemplary embodiment.

One important aspect of the interconnect arrangements 500, 600 according to the invention is that the  $\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$  material according to the  
35 invention, produced by means of a PECVD process, is used as the material for the layers 505, 507, 509, 510. Exposed surface areas in particular of the layers 507, 510 are reliably protected, by means of a selective deposition process during the subsequent formation of



the ozone/TEOS covering layer 516, against being undesirably covered with material of the covering layer 516, since this would lead to partial filling of the cavity 514. This would in turn undesirably increase the effective relative dielectric constant of the area between the interconnects 503. Owing to the provision of the layers 505, 507, 509, 510 composed of  $\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$  material, which, because of its material composition, is protected against selective deposition of material of the ozone/TEOS covering layer 516, the covering layer 516 is deposited selectively during the ozone/TEOS deposition process only on those surface areas of the supporting layer 511 which are composed of silane-based silicon oxide, so that the material of the covering layer 516 grows over the cavity 514, thus closing it.

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**List of reference symbols**

100	Layer arrangement
101	Silicon substrate
102	First copper interconnect
103	Second copper interconnect
104	$\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$ material
105	Silane-based silicon-oxide intermediate layer
106	Ozone/TEOS covering layer
107	Airgap
200	Electron-microscope photograph
201	Covering layer
202	Airgaps
203	Side wall cover
204	Dielectric
300	Electron-microscope photograph
301	$\text{Si}_{1.00}\text{O}_{1.90}\text{H}_{0.27}\text{C}_{0.045}\text{N}_{0.06}$ material
400	Electron-microscope photograph
401	Copper interconnects
500	Layer arrangement
502	Base substrate
503	Interconnect
504	First stop layer
505	First isolation layer
506	Second stop layer
507	Second isolation layer
508	Third stop layer
509	Third isolation layer
510	Buffer layer
511	Supporting layer
512	Fourth stop layer
513	Buffer-layer surface
514	Cavity
515	Electrical contact
516	Covering layer

- 517      Covering layer/supporting-layer surface
- 518      Fifth stop layer
  
- 600      Layer arrangement